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ANALYSIS OF FISSION RATIO DISTRIBUTION IN SPHERICAL LITHIUM METAL ASSEMBLY WITH A GRAPHITE REFLECTOR

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Analysis of Fission Ratio Distribution in Spherical Lithium Metal Assembly with a Graphite Reflector

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For the investigation of neutronics in the fusion reactor blanket, a spherical lithium assembly with a graphite reflector was prepared by piling up lithium and graphite blocks. The ratio of U-238 to U-235 fission rates was measured by micro fission chambers, and the result of the measurement was compared with that of the preliminary calculation. It has been shown that there is a large discrepancy between experiment and calculation, which is too large to be explained only by the experimental error.

In this paper, the calculational procedure is reviewed and probable causes of the calculational error are listed. Further calculation of the fission ratio is carried out employing refined methods and with varied calculational models.

As the result, it is concluded that the cause of the discrepancy is most likely the uncertainties of the nuclear data of the constituent elements of the assembly.

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黒鉛反射体付リチウム金属球体系における核分裂比分布の解析

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核融合炉ブランケットにおける中性子の挙動を調べる目的で，リチウム及び黒鉛ブロックを用いて黒鉛反射体付リチウム金属球体系を組んだ。^{238}Uと^{235}Uの小型核分裂計数管により^{238}U／^{235}Uの核分裂比を測定し，その結果を予備的な計算結果と比較したところ実験誤差では説明しえないほど大きな不一致が見られた。

本文では計算手法を検討し計算誤差の原因と考えられる項目を明らかにした。そしてより厳密な手法と異なる計算モデルを用いて核分裂比を再計算し計算誤差を調べた。

その結果上記不一致の原因は計算法に伴う誤差ではなく，実験体系に含まれる元素の核データの不確定性によるものと考えるに至った。

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I. INTRODUCTION

In order to investigate the behavior of neutrons in the fusion reactor blanket, several integral experiments on lithium metal assemblies have been carried out in Japan Atomic Energy Research Institute.[(1),(2),(3)]

A graphite reflector in the blanket is useful to improve the tritium breeding and the shielding. A spherical lithium metal assembly with a graphite reflector was prepared by piling up lithium and graphite blocks. A D-T neutron source is placed at the center of the assembly. The spatial distribution of the ratio of U-238 to U-235 fission rates in the assembly was measured by micro fission chambers. The fission ratio distribution was calculated by the one-dimensional transport code ANISN[(4)] with P_5-S_8 approximation using a 42 group neutron cross section set. A large discrepancy between the measured fission ratio distribution and the calculated one has appeared as shown in Fig. 1.[(2)] The difference is too large to be explained only by the experimental error. On the other hand, the measured fission ratio distribution agrees well with the calculated one in the lithium metal assembly without a graphite reflector as shown in Fig. 2.[(2)] From these two figures it is suspected that the reflected neutrons are not evaluated correctly.

The details of the experimental assembly and procedures have already been described in the previous papers.[(1),(2)] In this paper, after a brief description of the assembly the calculational procedures employed are reviewed and the probable causes of the calculational error are listed. Further calculations of the fission ratio distribution in the assembly with graphite reflector is carried out with improved cross section sets, a more accurate method and varied calculational models.

II. EXPERIMENTAL ASSEMBLY

A spherical lithium assembly is prepared by loading lithium blocks in drawers, which are then inserted into a matrix The lithium blocks are covered with 1 mm thick stainless steel. The drawers and the matrix are made of stainless steel. The assembly is surrounded with a graphite reflector prepared in the same manner as the lithium assembly but using graphite blocks. The assembly is located on the steel-grid floor, and the distance between the target and the nearest concrete floor or wall is more than 4 m.

A horizontal cross section of the assembly is shown in Fig. 3. Source neutrons are generated at the center of the assembly by a D-T reaction with a 300 KeV Cockcroft-Walton type accelerator. The experimental hole, through which micro fission chambers are traversed is 2 cm in diameter and is perpendicular to the direction of the incident D^+ beam. There is a central void region of effective radius of 10 cm, where neither lithium or graphite blocks are loaded. The effective thicknesses of the lithium region and the graphite region are 24.1 cm and 21.2 cm, respectively.

III. REVIEW OF THE PRELIMINARY CALCULATIONS

The calculational model for the experimental assembly is shown in Fig. 4. The mesh width used in the numerical calculation are also shown in the figure. The first two regions, i.e. source and void, consist of empty drawers and matrix tubes made of stainless steel. In the third and fourth regions, lithium and graphite blocks are loaded, respectively. The nuclide densities in each region are shown in Table I. It is assumed that the isotropic neutron source is uniformly distributed in the sphere of 0.5 cm radius.

The first 42 energy group neutron cross section set was prepared from ENDF/B-III[5] by SUPERTOG[6] using 1/E as the weighting function. The energy group structure which has some correspondence to the ABBN Set,[7] is shown in Table II. Legendre coefficients of up to P_5 were derived. The neutron flux was calculated by the one-dimensional transport code ANISN[7] with P_5-S_8 approximation. The fission rates of U-238 and U-235 were also calculated by the ANISN.[4] The second set of neutron cross section is derived by using the neutron energy spectrum at R = 15 cm as the weighting function. This neutron spectrum is obtained with the calculation using 1/E weighted cross sections.

In Fig. 1, the calculated ratios using 1/E and the neutron spectrum as the weighting functions are shown with solid line and dashed line, respectively. It is seen that better agreement with the measured ratio is obtained when spectrum weighted neutron cross sections are used. However, even with the use of spectrum weighted cross sections, the ratios of calculation to experiment, so called C/E values, are 0.87, 0.82, 0.66 and 1.12 at the distance of 15.6 cm, 26.6 cm, 36.4 cm and 46.1 cm from the source, respectively.

The cause of the above discrepancy was investigated from the viewpoint of experiment, and it is concluded that the difference cannot be explained only by the experimental error. Considering the fact that there had been a good agreement in the case of the lithium assembly without a graphite reflector (as shown in Fig. 2), it is presumed that the evaluation of the low energy reflected neutrons is not appropriate. There are several reasons for causing inaccurate calculational results:

(1) The wide lethargy width of 0.3466 and 0.7700 were used for low energy groups of 42 group neutron cross sections (as shown in Table II). This may have caused some error in the calculation of low energy neutrons.

(2) As shown in Fig. 5, the experimental configuration of the boundary of lithium and graphite cannot be taken into account in one-dimensional calculational model. Conserving the volume of lithium region and the void, a sphere surface with the effective radius of 34.1 cm was taken as the boundary.

(3) The P_5-S_8 approximation used in the calculation of the neutron flux may not be sufficient.

(4) The vacuum boundary condition is used in the calculation of the neutron flux and the room return neutrons have not been taken into account.

(5) Uncertainty in the nuclear data, especially those of carbon for neutrons with energy higher than 5 MeV should be questioned.

IV. REFINED CALCULATIONS AND DISCUSSIONS

Five probable causes for the error in the calculated results are listed in the Chapter III. The first four causes are investigated to see their effects on the calculated values of fission ratio.

(1) In order to investigate the effect of wide lethargy widths used for low energy groups, two sets of 100 group cross sections are derived by the procedure shown in Fig. 6. One of the 100 group sets is obtained from the DLC-2D Library.[8] In the processing of the library from ENDF/B-III, fission spectrum joined at 0.0674 MeV by a 1/E tail had been used as the weighting function. The other 100 group set with the same energy structure as the DLC-2D is obtained by using the neutron energy spectra as the weighting functions. Zone dependent cross sections for each nuclide were obtained by using the representative neutron spectrum of each zone as the weighting function, as shown in Table III.

The calculated fission ratios using the two 100 group neutron cross sections are shown in Fig. 7 together with the result of the 42 group calculation and the measured values. The three curves of the calculated ratios overlap in the void region and the inner part of the lithium region. In the outer part of the lithium region near the graphite, three curves begin to diverge, and the differences become larger in the graphite region.

The 42 group calculation gives the best agreement with the measured result. The ratio calculated with the 100 group zone dependent cross sections, which had been expected to give better agreement than the 42 group calculation, shows the largest discrepancy with the measured value. The ratio calculated with the DLC-2D cross sections is a little larger than the result obtained with the zone dependent cross sections.

(2) To take into account properly the lithium-graphite boundary configuration shown in Fig. 5, a three dimensional neutron transport calculation is necessary. As no such calculational technique is available at present, two types of one dimensional model are tested to see the effect of the boundary modelization on the calculated fission ratio. The one is a model with the outer radius of the lithium region increased to 35.9 cm, which is equal to the distance of the real boundary in the experimental hole. The other is the model with the mixed boundary region. In this model about 10 cm thick mixed region, with the average nuclide densities of the lithium and graphite regions, is placed between the two regions.

The results of the calculations employing two new one dimensional models are shown in Fig. 8 together with the previous calculational result and the measured values. The same 42 group neutron cross sections obtained by neutron spectrum weighting is used in the three calculations. The ratio calculated with the radius of the lithium region taken at 35.9 cm is in better agreement with the measured value than the previous result in the lithium region but the agreement is worse in the graphite region. The ratio obtained with the mixed boundary region is almost equal to that of the previous calculation.

It is seen that the difference in the model of the lithium and graphite region boundary is quite sensitive to the calculated ratio. But there is still some discrepancy in the lithium region even with the model of 35.9 cm radius for lithium region. It is unlikely that good agreement can be obtained both in the lithium and graphite region even with three dimensional calculations.

(3) The calculation with P_5-S_{16} approximation was made. By increasing the number of directional mesh points in the S_N approximation from 9 to 17, the calculated fission ratio became larger by only a few percent at most and there still exsists a large discrepancy with the measured ratio.

(4) The effect of the room return neutrons on the fission ratio is evaluated by carrying out a calculation with the calculational model with concrete wall placed 4 m away from the source. It is seen that the calculated ratio in the outer part of the graphite was lowered by several percent when the room return neutron is taken into account. The better agreement with the measured ratio in the shape of the distribution is obtained but there still remains a large discrepancy.

V. SUMMARY

The probable causes of the error in the preliminary calculations of the fission ratio in the spherical lithium assembly with a graphite reflector has been investigated.

It is shown that (1) the use of 100 group zone dependent cross sections gives an even larger discrepancy with the measured value, (2) the one dimensional calculation is not sufficient to take into account the irregular configuration of lithium-graphite boundary, (3) the number of directional mesh points seems to be adequate, and (4) the consideration of the room return neutrons reduces the discrepancy in the graphite region by several percent.

Although there still remains some ambiguity due to the inadequacy of the calculational methods, it is concluded that the discrepancy between the calculated and measured fission ratio cannot be explained by either the error in the experiment or the error in the calculational procedure. Thus it is most likely that the discrepancy is caused by the uncertainties in the nuclear data used. Especially the energy and angular spectra data of the secondary neutrons from inelastic and (n, 3α) reactions of carbon are questionable.

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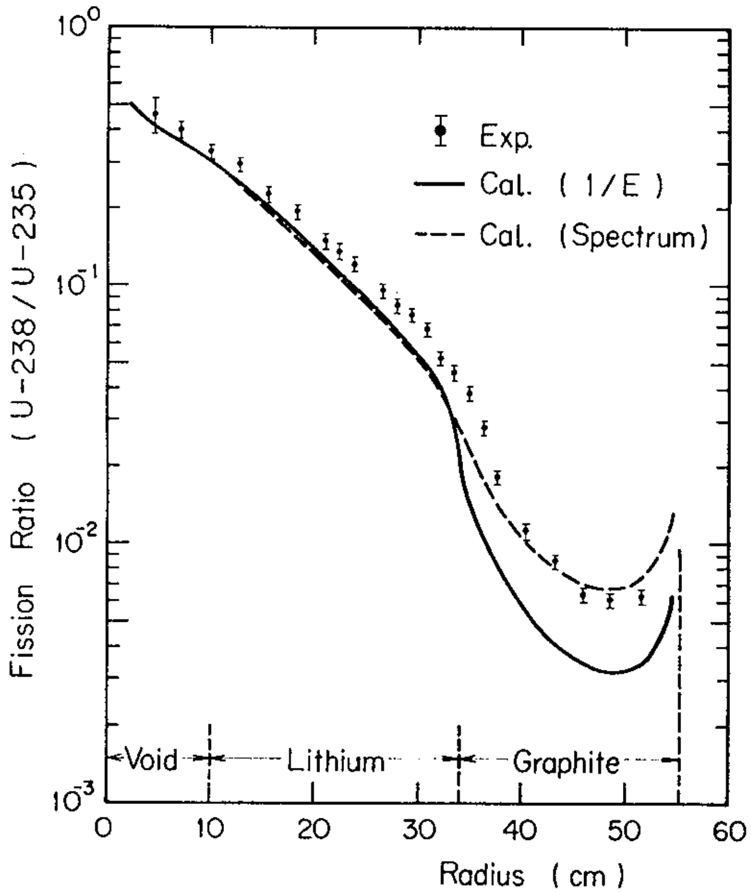

Fig. 1 Fission Ratio Distribution in the Spherical Lithium Assembly with a Graphite Reflector.

The solid line and dashed line are the calculated ratios using 1/E and the neutron energy spectrum as the weighting function, respectively.

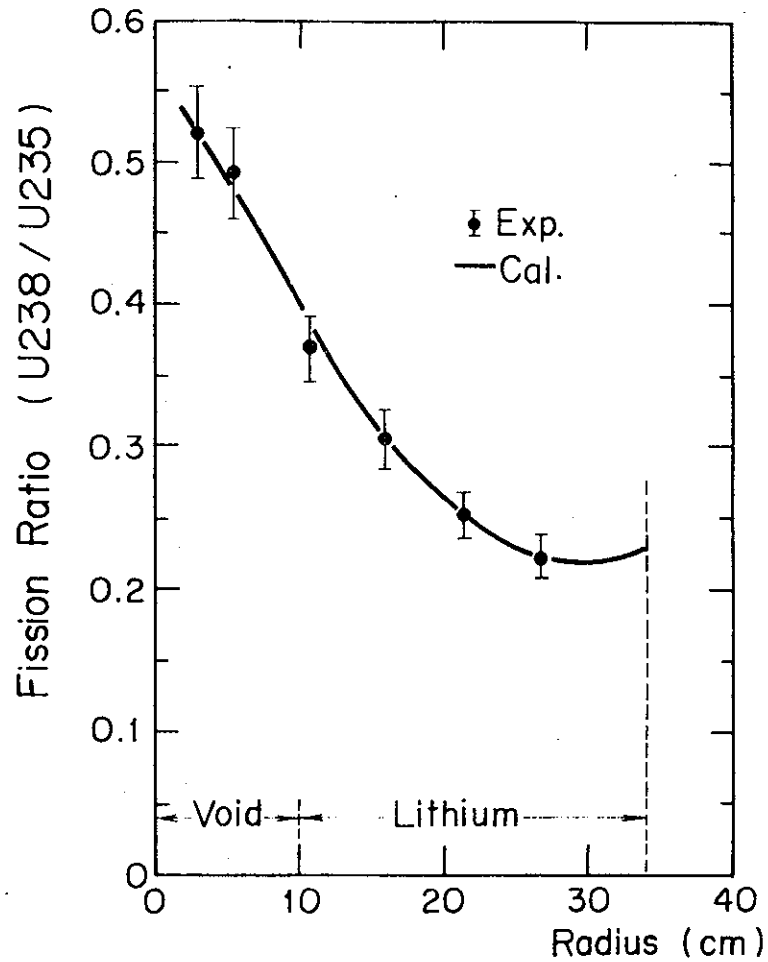

Fig. 2 Fission Ratio Distribution in the Spherical Lithium Metal Assembly.

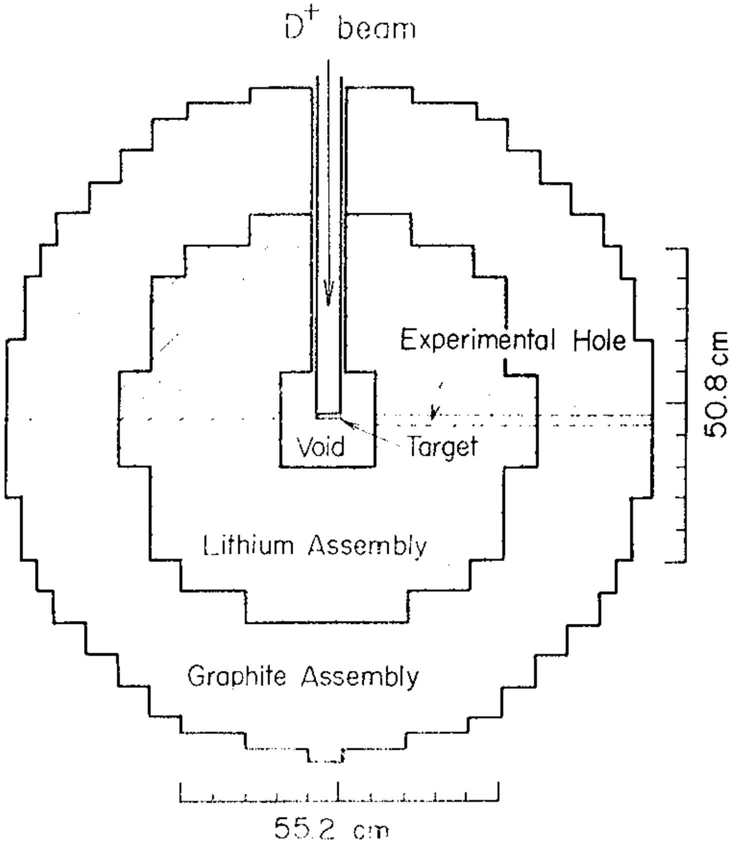

Fig. 3 Horizontal Cross Section of the Spherical Lithium Metal Assembly with a Graphite Reflector.

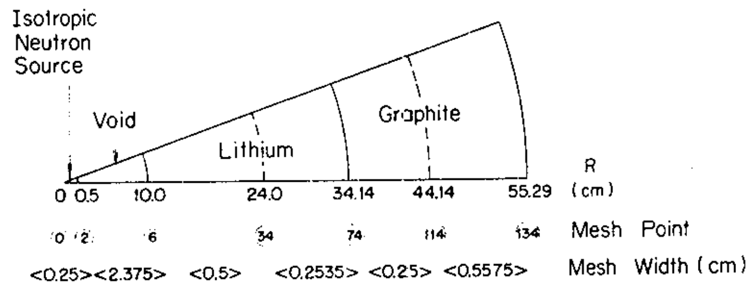

Fig. 4 Calculational Model of the Spherical Lithium Metal Assembly with a Graphite Reflector.

Table I Nuclide Densities of the Assembly

Region	Nuclide Density (atoms/cm^3 x 10^{24})					
	^{6}Li	^{7}Li	^{12}C	Cr	Fe	Ni
Source				0.001827	0.006652	0.0007964
Void				0.001827	0.006652	0.0007964
Lithium	0.002507	0.03128		0.003165	0.01117	0.001449
Graphite			0.07345	0.001827	0.006652	0.0007964

TABLE II GROUP STRUCTURE OF 42-GROUP SET FOR FUSION REACTOR CALCULATION (15.0 MeV-Thermal)

i	E_L MeV	ΔU	Corresp. ABBN	i	E_L	ΔU	Corresp. ABBN
1	13.720	0.08918		22	0.200	0.3466	7
2	12.549	〃		23	0.141	〃	
3	11.478	〃		24	0.100	〃	8
4	10.500	〃		25	46.5 KeV	0.77	9
5	9.314	0.1199		26	21.5	〃	10
6	8.261	〃		27	10.0	〃	11
7	7.328	〃	1	28	4.65	〃	12
8	6.500	〃		29	2.15	〃	13
9	5.757	0.1214		30	1.00	〃	14
10	5.099	〃		31	0.465	〃	15
11	4.516	〃	2	32	0.215	〃	16
12	4.000	〃		33	0.100	〃	17
13	3.162	0.2350		34	46.5 eV	〃	18
14	2.500	〃	3	35	21.5	〃	19
15	1.871	0.2899		36	10.0	〃	20
16	1.400	〃	4	37	4.65	〃	21
17	1.058	0.2798		38	2.15	〃	22
18	0.800	〃	5	39	1.00	〃	23
19	0.566	0.3466		40	0.465	〃	24
20	0.400	〃	6	41	0.215	〃	25
21	0.283	〃	7	42	THERMAL	〃	T

Table III Neutron Spectra Used as the Weighting Functions to Obtain Zone Dependent Cross Sections

Nuclide	Zone	Radius (cm) Inner	Radius (cm) Outer	Neutron Spectrum ϕ (R)
Cr, Fe, Ni	Source, Void	0.0	10.0	ϕ (5 cm)
	Lithium	10.0	34.1	ϕ (20 cm)
	Graphite	34.1	55.3	ϕ (44 cm)
^6Li, ^7Li	Lithium I	10.0	24.0	ϕ (18 cm)
	Lithium II	24.0	34.1	ϕ (30 cm)
C	Graphite	34.1	55.3	ϕ (44 cm)
^{235}U, ^{238}U *	Lithium I	10.0	24.0	ϕ (18 cm)
	Lithium II	24.0	34.1	ϕ (30 cm)
	Graphite	34.1	55.3	ϕ (44 cm)

* Zone dependent fission cross sections for ^{235}U and ^{238}U are calculated.

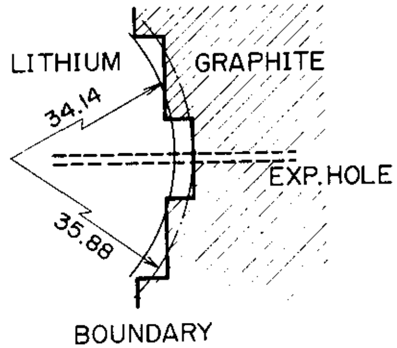

Fig. 5 Configuration of the Boundary Between the Lithium and the Graphite Regions.

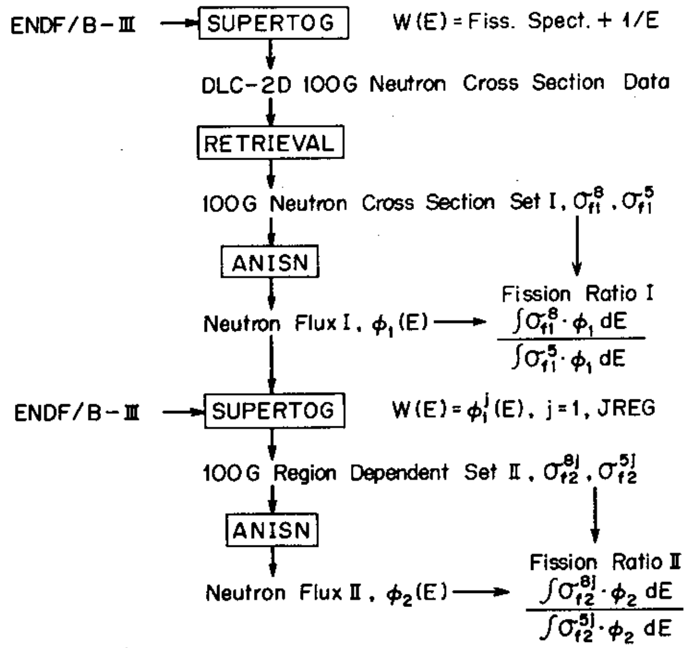

Fig. 6 100 Group Calculational Flow-Chart.

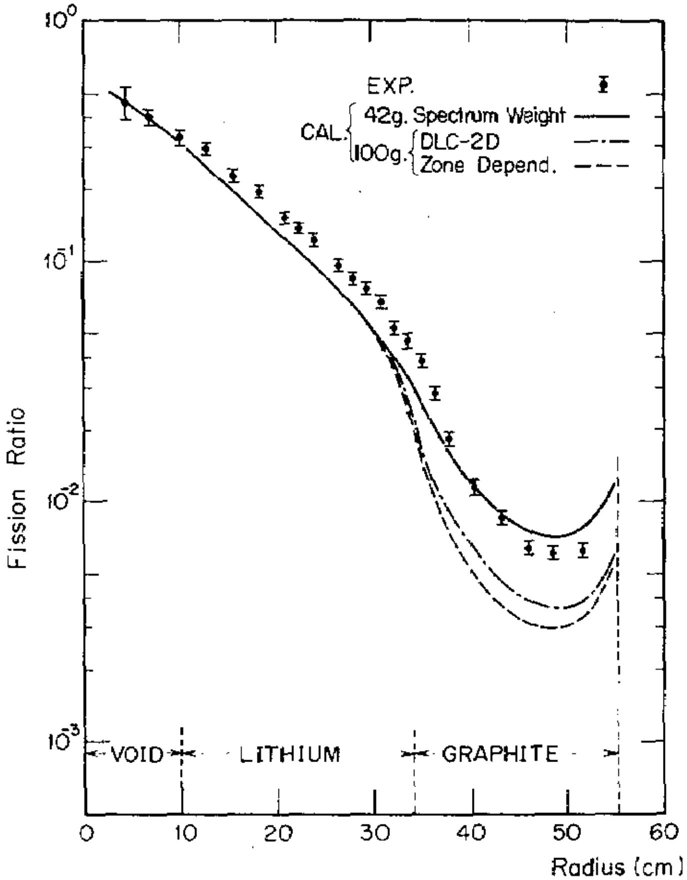

Fig. 7 Fission Ratio Distribution by 100 Group Calculations.

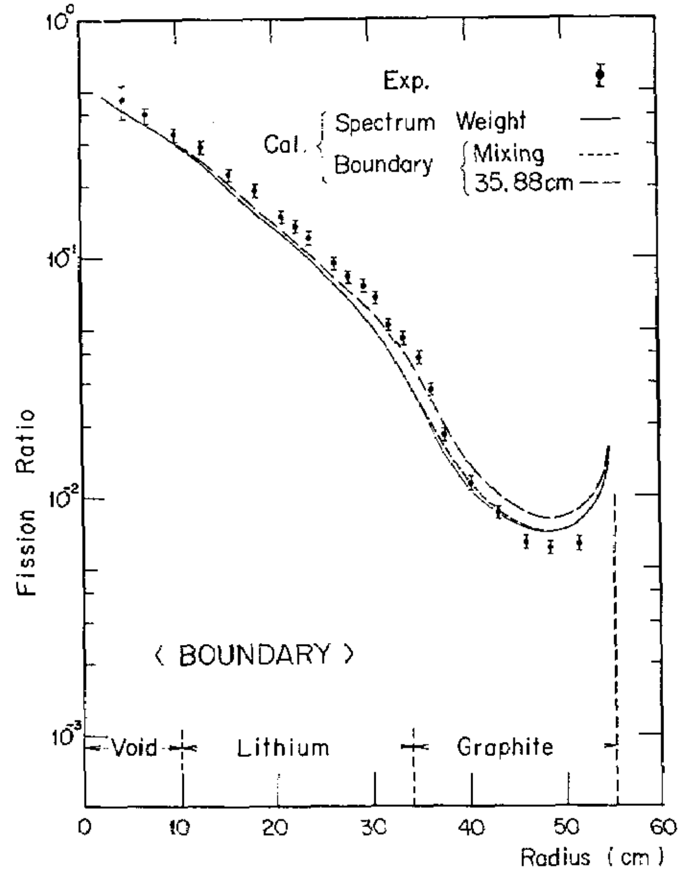

Fig. 8 Change of Fission Ratio Distribution with Varied Calculational Model.